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An investigation of three methods of mesh size measurement

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Abstract

This report presents measurements on netting typical of cod-ends in European Union (EU) demersal fisheries with mesh sizes in the range 70–120 mm and twine thickness from 2.5 to 6.1 mm.

Polythene and nylon netting is considered. The aim of the study is to assess the magnitude and some of the causes of variance in the measurement of mesh by two methods: the EU wedge gauge and ICES gauge. The use of a tape measure laid along a series of meshes is also discussed.

It has been reported previously (e.g. Parrish et al., 1956) that when a gauge is inserted into the mesh by force of hand the measured mesh size has greater variance than when it is obtained with other methods.

Both the ICES gauge and the wedge gauge produce reliable measurements under consistent conditions. The tape measure is considered less suitable for mesh size measurement because the reading is a function of twine thickness.

There are differences between the 4 kg spring-loaded ICES gauge and the wedge gauge with a 5 kg weight of approximately 3–5%.

The measured mesh size increases with the force exerted by the gauge on the mesh so that a consistent applied force is essential in order to reduce the variance of measurements.

When meshes are measured under controlled conditions the standard deviations indicate that variation in mesh size is mainly due to netting manufacture. There is no significant difference in variance with different gauges or with different weight or tension applied for a given method.

Keywords: Mesh size; Methods of measurement

1. Introduction

Mesh size, or more properly, mesh opening (Fig. 1) is one of the key factors in the design of fishing gear affecting the escape of fish from cod-ends and hence cod-end selectivity

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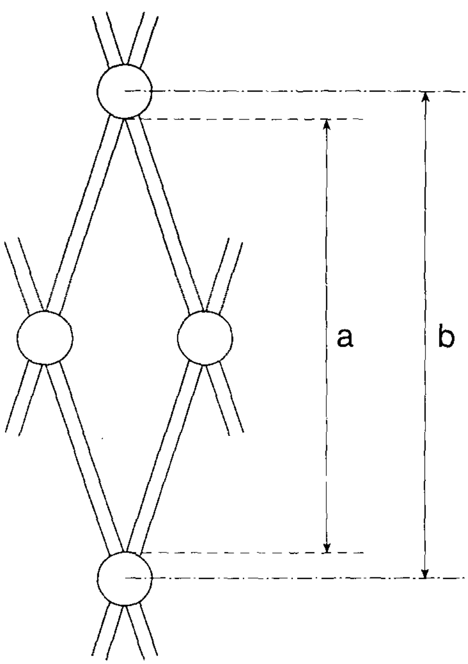

Fig. 1. Alternative definitions of mesh size.

(Reeves et al., 1992). By regulating mesh size, fisheries managers aim to control the mortality caused by commercial fishing fleets. Hence, reliable measurements of mesh size are needed by scientists when estimating fishing mortality in stock assessment predictions and also by enforcement officers and net makers to ensure that commercial fishermen use cod-ends which comply with the regulations.

Many comparative measurements of mesh size were made in ICES member countries during the 1950s and 1960s (Roessingh, 1961; Bohl and Nomura, 1961; Parrish and Pope, 1961), with the main aims of finding a better measuring method which could be accepted by both enforcement officers and scientists and also of standardising gauges used in the ICES and ICNAF areas (ICNAF, 1958). The Westhoff gauge (Westhoff et al., 1962) was chosen to be the standard ICES gauge. However, it was found difficult to reconcile the need of scientists for precision and of enforcement agencies for practicality. The pragmatic approach is explained clearly by Medico and Levie (1967). The legally defined method of measuring mesh size in Europe continues to be the wedge gauge (Anonymous, 1984) which has the advantage of simplicity of use. The International Standards Organisation (ISO) did not adopt a standard method for mesh size measurement despite much discussion and preparation of a draft document in the 1970s. Both methods however, aim to measure the same characteristic of the mesh, namely the opening of the mesh between opposite knots (Fig. 1) in the N-direction (as defined in ISO, 1974). This quantity is the most significant factor determining the size of the hole through which fish can escape during the fishing process.

Net-makers, however, often measure mesh size by a third method. They measure the length of mesh (ISO, 1974) from knot centre to knot centre (Fig. 1) by dividing the distance along a certain number of fully extended meshes by the number of meshes. This has been accepted as the legal measure of mesh size in the past in the United Kingdom (Anonymous, 1933), expressed as a count of a maximum number of rows of meshes per unit length.

The mesh size of a cod-end is not a single and fixed value for all time. A set of 20 measurements taken along a cod-end will show some variation because net making machines do not always produce a uniform product and heat and other treatments subsequent to manufacture may be uneven over the netting surface. Mesh size may vary with position in the cod-end due to variations in the load on individual meshes (e.g. near the selvedge or the aft end). Sets of measurements on the same cod-end but taken at different times may also show variance because the amount of usage which the netting has had and the environmental conditions at the time of measurement can affect mesh size. Abrasion of twine and absorption of sand can cause reductions in mesh size (Klust, 1982; Strange, 1984; Fonteyne, 1986). Finally, the registered size may depend on the type of gauge or other method used.

The present aim is not to find a better measurement method but to explore the extent and causes of variation in measured mesh size. Comparisons between three methods are made for a range of twine types and sizes used in cod-ends in the UK. Careful consideration has been given to the conditions under which the measurements were made. The effects of the force exerted by the gauge, of the netting tension during measurement, of wetting the netting and of choice of direction of rows of meshes to be measured are all investigated. It is important to reconsider the measurement of mesh size now because of the recent and continuing changes in materials used for cod-end netting, particularly the increase in twine thickness and use of composite materials.

2. Materials and methods

2.1. Netting samples

Twenty-two pieces of netting were used for the tests. The samples (Table 1) were cut into pieces ranging from 20 to 30 meshes in length by 20 to 35 meshes in width depending on the mesh size.

Sample 15 comprises two twines of different specification used to make up a double twine. Samples 19 to 22 were taken from real cod-ends which have been used on fishing trips by the Marine Laboratory; the other samples were from unused netting.

The thickness of the twines was measured using an optical method (Ferro, 1989), except for the nylon twines (samples 17 and 18) which were measured by a micrometer, because they were near the upper size limit of 7 mm suitable for this optical method. The nominal

Table 1
Description of the netting samples. The construction of each netting yarn is indicated by $\times a \times b+c$ where a is the number of single yarns or filaments in the first fold, b is the number of folded yarns and c is the number of single yarns or filaments in the core of a braided yarn. Nominal mesh size is that quoted by the net manufacturer, the stretched inside mesh opening between opposite knots

No.	Description		Rtex (measured)	Twine thickness (mm)		Nominal mesh size (mm)
				Nominal	Measured	
1	ST PE	×9×3	1765	–	1.76	80
2	ST PE	×13×3	2743	–	2.22	80
3	ST PE	×15×3	3171	–	2.37	80
4	ST PE	×20×3	4000	–	2.69	80
5	SB PE	×2×16+11	2555	2.5	2.14	100
6	SB PE	×3×16+7	4200	3.0	2.86	100
7	SB PE	×3×16+10	4643	3.5	3.00	70
8	SB PE	×4×16+7	5150	3.5	3.27	80
9	SB PE	×4×16+8	6022	4.0	3.53	80
10	SB PE	×4×16+12	5830	4.0	3.30	100
11	SB PE	×4×16+12	5830	4.0	3.30	110
12	SB PE	×6×16+9	9676	5.0	4.28	80
13	DB PE	×4×16+8	5760	4.0	3.53	80
14	SB PE	×6×16+28	8320	4.5	3.86	100
15	DB PE	×9×16+12	11910	6.0	4.63	100
		×7×16+18	10778	6.0	4.42	100
16	SB[b]	×4×16+24	6967	4.0	3.53	150
17	SB PA	×13×16+0	14506	6.0	6.05	130
18	DB PA	×11×16+0	12700	6.0	6.05	110
19[a]	DB PE		–	4.0	–	90
20[a]	DB PE		–	4.0	–	100
21[a]	DB PE		–	4.0	–	110
22[a]	DB PE		–	4.0	–	120

[a]Used cod-ends.
[b]A mixture of PA and PES.
ST, single twisted; PE, polyethylene; SB, single braided; PA, nylon; DB, double braided; PES, polyester.

twine thickness is as quoted by the supplier and may be based on the maximum outside diameter. It is generally larger than the thickness measured by the optical method.

2.2. Equipment

A 1.8 m×1.0 m tubular frame (Fig. 2) was mounted horizontally in order to hold a sample of netting while the meshes were measured. The netting sample was connected to the frame by cable ties along three of the four sides (a) in such a way that the netting could move freely. Along the fourth side (b) the netting was attached, again by cable ties, to a bar which could slide along the frame. The bar was connected by a rope hanging over a pulley (c) to a freely hanging weight (d). By applying an appropriate weight a specific netting tension could be achieved.

An in-line load cell was used at point (e) (Fig. 2) to measure the tension applied directly between the netting and the pulley so that the force applied per mesh was known. It was

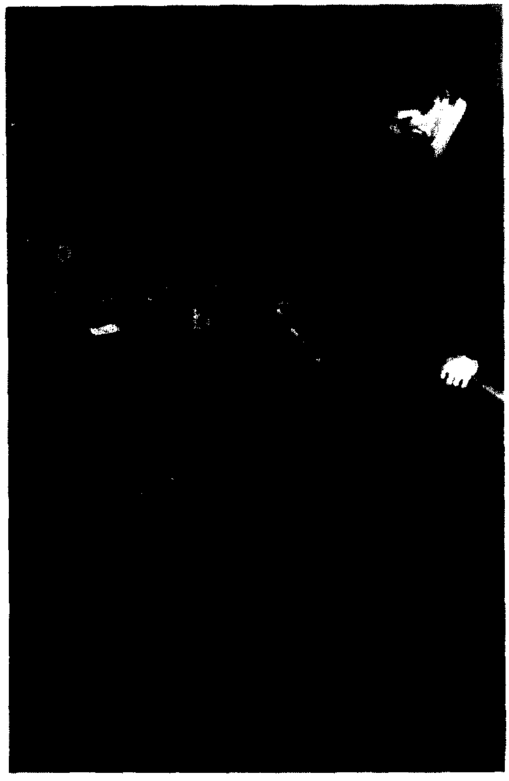

Fig. 2. Frame and tensioning system to hold netting samples.

found that there was a loss along the length of the netting sample of approximately 7% due to friction in the cable ties holding the netting along the lateral edges of the frames.

2.3. Measurement of mesh size

2.3.1. Wedge gauge

Standard EU wedge gauges (Fig. 3) as employed by enforcement officers in the UK were used. A range of weights of 2, 5 and 10 kg were chosen in this experiment to assess the effect of the weight. The gauge itself has a significant weight which is not specified in the legislation (Anonymous, 1984) defining the measurement method. The legislation defining the gauges specifies only the thickness and taper rate of the wedge and gives two alternative profiles. Post (1987) showed that different measurements were obtained with EU gauges manufactured in different EU member countries. There were differences in shape, graduations and weight of the gauges.

The weight of the brass EU gauges used in the UK vary from 0.24 to 1.15 kg (Table 2).

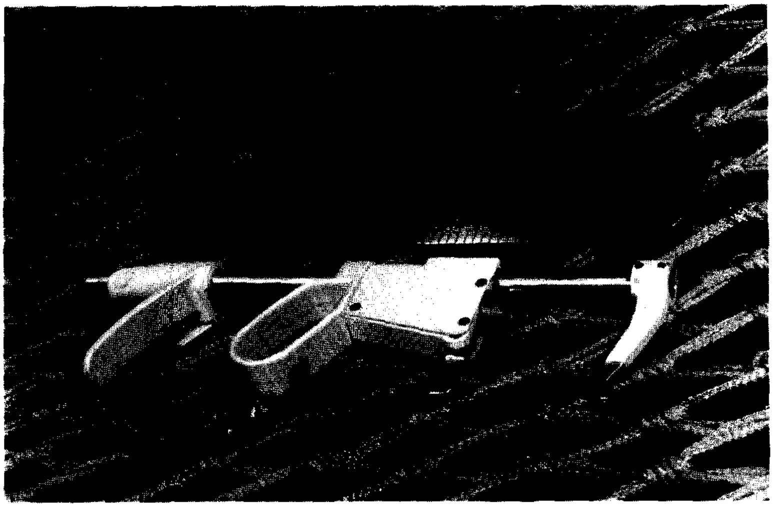

Fig. 3. ICES spring-loaded gauge (lower) and EU brass wedge gauge.

2.3.2. ICES gauge

The gauge (Fig. 3) recommended by ICES (Westhoff et al., 1962) was used. The force applied by the ICES gauge can be changed by adjusting the spring mechanism and the effect on mesh size measurement of using 2, 4 and 8 kg spring forces has been studied.

Both the wedge and the ICES gauges provide similar measurements in that the mesh is stretched open by force. There is a difference in the direction of initial applied force, however. The force exerted by the ICES gauge is in the plane of the netting, while the wedge gauge provides a force (a weight) normal to the measurement direction when the netting is held horizontally. Hence the force exerted by the wedge in the netting plane will depend on, for example, the friction between the twine and wedge and therefore might be expected to vary with material and its condition.

2.3.3. Tape measure

Some net makers prefer to measure mesh size by calculating the mean size of a series of stretched meshes, as described in the Introduction. This provides a measurement of length of mesh (defined in ISO, 1974) from knot centre to knot centre and is different from the

Table 2
The weights of official EU mesh gauges used in the UK

Mesh size range (mm)	Weight of gauge (kg)
8–70	0.24
60–110	0.37
110–182	0.78
176–244	1.15

Table 3
Variation of mean mesh size with number of meshes measured with standard deviation (SD) for sample 10 (100 mm SB 4 mm PE netting)

	No. measured				
	20	40	60	100	120
Mesh size (mm)					
Mean	97.45	97.43	97.43	97.38	97.34
SD	2.35	1.97	1.87	1.94	1.97

opening of the mesh measured by the wedge and ICES gauges (Fig. 1) as it includes the knot diameter and will be dependent on twine thickness, twine type and knot type. While length of mesh may be useful for net design as it indicates the stretched length of a panel of netting, the mesh opening is a more appropriate quantity to measure for cod-ends since it is more closely related to the selectivity of the netting (ICNAF, 1958).

2.4. Choice of measurement technique

Because the experiment was aiming to assess variability in the measurement of mesh size it was important to ensure that a standard technique was used for all measurements.

All samples were measured dry as no consistent significant difference was found between wet and dry measurements of mesh size for five polyethylene samples after 24 h soaking. This result suggests that the gauges were not affected by the wet or dry condition of the netting. It was not the intention to determine whether the mesh size changed but whether the operation of the gauges was affected by water. It was also considered easier to maintain consistent measuring conditions when the netting was dry. The twines were measured at room temperature which varied from 15 to 20°C during the trials.

The netting could be tensioned in the frame (see Section 2.2) in both longitudinal and transverse directions. This allowed the netting to be set at a fixed setting angle before mesh measurement so that the forces acting on the mesh bars were consistent for all measurements (Fig. 2). An initial setting angle of 60° was chosen. In this way the tension in the netting was evenly distributed over all the meshes of the sample. During measurement by any of the gauges the mesh closed under the action of the force applied by the gauge so that the setting angle was reduced to its effective minimum.

An initial test was made with the 4 kg ICES gauge to assess how many individual measurements were needed to obtain a representative mean mesh size for a piece of netting. Up to 120 meshes (six independent sets of 20 consecutive meshes) were measured for this purpose. The difference in mean mesh size after 20 meshes and after 120 meshes have been measured is very small, only 0.11 mm or less than 0.2% (Table 3).

Taking the mean value of 40 measurements was considered to be sufficient to represent the mesh size of the netting samples in this experiment. The EU requirement to prove whether a mesh size is legal is for the measurement of three sets of 20 consecutive meshes.

Finally it was necessary to decide what longitudinal tension should be applied to the netting sample. A set of 40 meshes of sample 8 (80 mm single braided polyethylene netting)

Table 4
Analysis of variance showing the difference in ICES gauge mesh size as netting tension is varied for sample 8. Significance at the 95% level ($P = 0.05$) is indicated by an asterisk

	Mean mesh size (mm)			
	76.5	77.0	77.8	78.1
Netting tension	1500	1000	500	0
1500	–	0.5	1.3*	1.6*
1000		–	0.8	1.1*
500			–	0.3

was measured under a range of four netting tensions from 0 to 1500 g per mesh using the 4 kg ICES gauge. The analysis of variance (Table 4) indicates that the difference in measured mesh size due to different netting tensions is not significant unless the netting tension between two measurements changes by more than 1000 g per mesh. A standard tension of 500 g per mesh was chosen and it was applied by adding weight at (d) (Fig. 2).

Two measurement methods were used. The first was used when the tape measure was being compared with the ICES gauge measurement. The netting was extended under a load of 500 g per mesh longitudinally but was not attached to the sides of the frame (a) (Fig. 2). Thus, no transverse load was applied in the T-direction so that the netting was effectively fully extended in the N-direction. The distance along 20 consecutive meshes was measured in the N-direction. This value divided by 20 was taken as the length of mesh, that is, the distance between opposite knot centres in the N-direction. The same netting tensioning was maintained while measurements with the ICES gauge were taken for comparison.

The second method was used in all other tests using the wedge and ICES gauges. The netting was connected to the frame sides by cable ties and a load of 500 g per mesh was applied to the netting in the N-direction. Even distribution of load and a mesh setting angle of 60° were achieved by adjusting the cable ties along the four sides (Fig. 2). The choice of meshes to be measured was in accordance with the EU regulation (Anonymous, 1984) for determining the mesh size of fishing nets.

2.5. *Repeatability of measurements*

Having defined the measurement methods a further test was made to check whether repeated measurements on the same meshes would provide similar results.

The 4 kg ICES gauge and the EU gauge with 5 kg weight were used on the same set of 40 meshes (Table 5). It is demonstrated that there is little change in measured mesh size when the measurements are repeated using the same gauge. The maximum differences are 0.4% for the ICES gauge and 0.5% for the wedge gauge and these can be neglected. However, the difference in measurements between the two gauges is significant. This point is considered in more detail later.

Table 5
Change of mesh size by repeated measurement

Sample	Test (procedure)			
	1 (ICES)	2 (ICES)	3 (Wedge)	4 (Wedge)
110 mm DB 6 mm				
Nylon	103.1	103.1	106.5	106.7
SD	2.7	2.7	2.5	2.5
100 mm DB 6 mm				
PE	98.4	98.8	102.8	103.3
SD	3.0	2.9	3.1	3.1

3. Results and analysis

3.1. Comparison of ICES and EU wedge gauges

For scientific work the ICES gauge is normally used with a spring force of 4 kg. European Union legislation specifies that the wedge gauge should be used with a 5 kg weight (for mesh sizes over 36 mm) to obtain results unbiased by the operator.

For each netting sample, the same set of meshes was measured using the 4 kg ICES gauge, followed by the 5 kg EU gauge, using the method described in Section 2.4.

The EU gauge with 5 kg weight gives significantly larger values of opening of mesh than the ICES 4 kg gauge ($P<0.01$). The ICES gauge measurement is between 1.7 and 5% lower than the wedge gauge measurement (Table 6). Similar differentials between these types of gauges have been reported in the past (e.g. Von Brandt and Bohl, 1959). A linear regression ($r^2=0.996$) of the measurements using the 4 kg ICES gauge and the 5 kg wedge gauge was found (Fig. 4) to have the following form

$$W=1.01I+2.96$$

where W and I are the mesh sizes (mm) measured by the wedge and ICES gauges, respectively. An additional term in twine thickness in this regression was found to be not significant.

Using a constant applied force under standard conditions provides mesh measurements which have a coefficient of variation (standard deviation/mean mesh size) typically between 1 and 3%. The maximum coefficient of variation was 3.5%. This applies to the EU wedge gauge as well as the ICES gauge used in scientific work. The main cause of this variation is not the type of gauge since the variation coefficients for the two gauges are highly correlated (Fig. 5). Hence, the important conclusion is reached that either the two methods have similar large variance or the variance is attributable mainly to the properties of the netting.

There are possible sources of variance in the methodology which may be common to both wedge and ICES gauges. Schwalbe and Werner's observation (1977) was confirmed that during insertion of a gauge into a mesh its edge could lie against the knot in a variety of configurations. However, it is unlikely that such random effects would lead to the highly correlated variation coefficients (Fig. 5).

Sheet netting manufacture is not a precise process and there will be a consequent variation in mesh size in any netting sample. The variation may also be dependent on twine and netting characteristics such as twine material, thickness and hardness of twist, as noted by Beverton and Bedford (1958). No significant relation was found, however, between coefficient of variation of mesh size and twine thickness or number of yarns for polyethylene twine. Not enough samples of different materials were tested to look for a relation with other characteristics.

3.2. Comparison of ICES gauge and tape measure

Measurements of mesh opening using the 4 kg ICES gauge were compared with measurements of length of mesh obtained by tape measure (Table 7). No transverse force was applied to the netting during these measurements (see Section 2.4). A longitudinal tension of 500 g per mesh in the N-direction was applied during the measurements. For single braided PE twine, a linear regression ($r^2=0.995$) relating the two measurements was found to have the following form

$$N=1.37+1.02I+2.9d$$

Table 6

Mesh size measured with 4 kg ICES gauge and wedge gauge with 5 kg weight for a range of netting samples. Standard deviations (SD) and coefficient of variation (COV) (100 × SD/mean) are given and the difference between the two measurements expressed as a percentage

Sample no.	Measured thickness (mm)	4 kg ICES			5 kg EU			Difference EC − ICES (mm)	100* (EC − ICES)/EC (%)
		Mesh size	SD (mm)	COV (%)	Mesh size	SD (mm)	COV (%)		
1	1.76	76.7	1.27	1.7	80.5	1.34	1.7	3.8	4.7
2	2.22	74.6	1.04	1.4	78.5	0.99	1.3	3.9	5.0
3	2.37	75.3	1.27	1.7	79.2	1.21	1.5	3.9	4.9
4	2.69	76.5	0.78	1.0	79.4	1.09	1.4	2.9	3.7
5	2.14	94.3	0.92	1.0	98.9	1.02	1.0	4.6	4.7
6	2.86	96.5	1.88	2.0	100.9	2.11	2.1	4.4	4.4
7	3.00	66.2	1.54	2.3	69.6	1.71	2.4	3.4	4.9
8	3.27	77.8	2.4	3.1	80.8	2.8	3.5	3.0	3.7
10	3.30	97.0	1.86	1.9	100.1	1.73	1.7	3.1	3.1
11	3.30	105.1	2.00	1.9	108.8	1.92	1.8	3.7	3.4
12	4.28	79.7	1.38	1.7	82.7	1.31	1.6	3.0	3.6
13	3.53	75.4	1.26	1.7	79.0	1.27	1.6	3.6	4.6
14	3.86	100.2	1.12	1.1	103.3	1.22	1.2	3.1	3.0
15	4.63/4.42	98.8	2.93	3.0	102.8	3.10	3.0	4.0	3.9
16	3.53	143.4	2.24	1.6	147.5	2.26	1.5	4.1	2.8
17	6.05	124.4	3.17	2.6	126.6	3.08	2.4	2.2	1.7
18	6.05	103.1	2.74	2.6	106.5	2.51	2.4	3.4	3.2
19	–	82.5	1.52	1.8	85.8	1.69	2.0	3.3	3.8
20	–	92.2	1.97	2.1	95.2	2.22	2.3	3.0	3.2
21	–	104.7	1.38	1.3	108.1	1.66	1.5	3.4	3.1
22	–	112.2	2.15	1.9	116.3	2.31	2.0	4.1	3.5

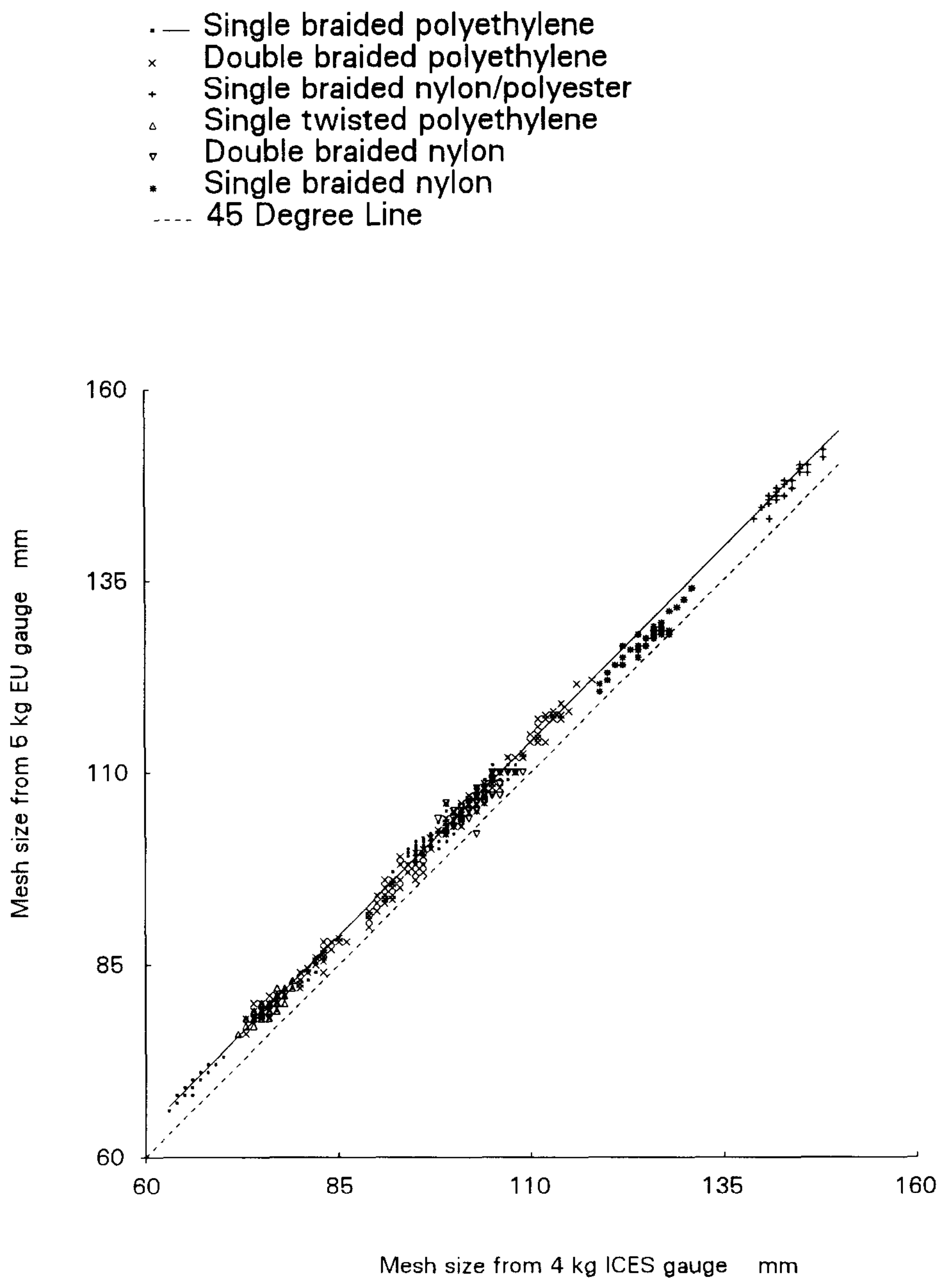

Fig. 4. Comparison of ICES and EU wedge gauges.

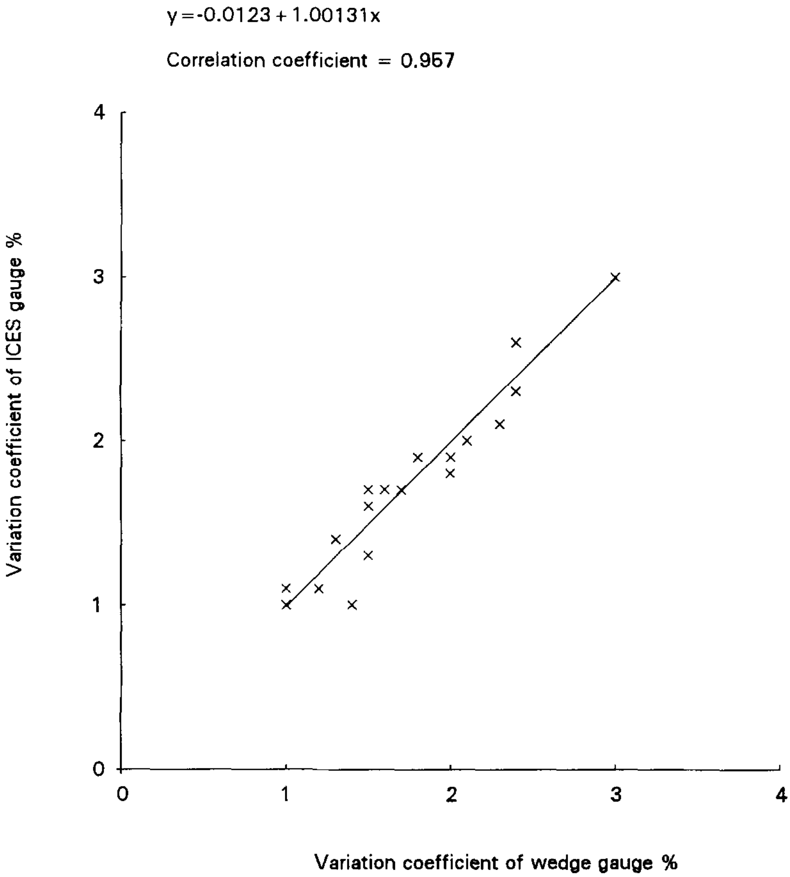

Fig. 5. Relationship between coefficients of variation for two mesh gauges.

Table 7
Mesh sizes measured by tape measure and 4 kg ICES gauge for all the single braided polyethylene netting samples

Sample no.	Measured thickness (mm)	Mesh size (mm)		
		Nominal	Tape measure	4 kg ICES gauge
5	2.14	100	103.8	94.1
6	2.86	100	107.0	96.9
7	3.00	70	78.0	65.9
8	3.27	80	85.7	74.9
9	3.53	80	88.6	75.1
10	3.30	110	119.5	106.2
11	4.28	80	85.0	80.1
13	3.86	100	112.9	98.0

Table 8
Effect of longitudinal netting tension on mesh size (mm) of sample 8 (80 mm SB 3.5 PE) for two gauge types

Gauge	Tension (g per mesh)		
	500	1000	1500
4 kg ICES gauge	77.8	77.0	76.5
SD	2.4	2.3	2.3
5 kg Wedge gauge	80.8	81.0	81.1
SD	2.8	2.7	2.7
Ratio: ICES/wedge	0.963	0.951	0.944

where N is length of mesh between knot centres (mm), I is opening of mesh measured by 4 kg ICES gauge (mm) and d is measured twine thickness (mm). The term in twine thickness is significant and this clearly shows that the opening of mesh (as measured by ICES gauge) and the length of mesh (tape measure) are related by the knot diameter which is approximately $3 \times$ twine thickness.

3.3. Effect of netting tension on ICES and wedge gauge measurements

The effect of varying the tension in the netting was investigated. A load cell was placed in line with the tensioning mechanism to check the horizontal longitudinal load applied to one end of the frame holding the netting sample. A series of 40 mesh measurements was made at tensions of 500, 1000 and 1500 g per mesh using both gauges, on sample 8 (80 mm single braided polyethylene netting).

The effect was found to be dependent on the gauge (Table 8). When the wedge gauge is used, analysis of variance shows no significant effect of netting tension on the measurement ($P=0.508$). Change of mean mesh size due to change in twine tension from 500 to 1500 g per mesh is very small (0.3 mm). When the ICES gauge is used, however, there is a tendency for the mean measurement to decrease as the netting tension increases. Mean mesh size reduces significantly ($P<0.05$) by approximately 1.5% kg^{-1} increase in tension per mesh.

The cause may be the initial force required to separate the two twines close to the knot as the gauge finds its final position. As the netting tension increases so the gauge has to exert a larger force to separate the twines near the knot. The spring mechanism will therefore be triggered earlier, giving a smaller reading of mesh size. The EU gauge with the attached weight applies a larger force during the whole time that the gauge is being inserted and its final position in relation to the knot may be less affected by netting tension.

3.4. Effect of force applied to ICES and wedge gauges

The spring in the ICES gauge determines the longitudinal load applied to the mesh at the time the reading is taken. Three similar ICES gauges were prepared with springs set at 2, 4

Table 9
(a) The increase in size of mesh with gauge force for five samples

	Sample no.				
	4	13	14	15	18
Material	PE	PE	PE	PE	PA
Twine	ST	DB	SB	DB	DB
Thickness (mm)	2.69	3.53	3.86	4.63/4.42	6.05
Nominal mesh size (mm)	80	80	100	100	110

(b) Mesh size (mm)

Gauge type	Force (kg)	Sample no.				
		4	13	14	15	18
ICES	2	73.1	70.3	96.4	93.1	97.3
	4	76.4	75.6	100.6	99.6	103.4
	8	78.4	77.6	103.3	103.1	107.3
EU wedge	2	76.1	74.9	97.8	99.3	102.2
	5	79.2	78.8	103.7	103.2	106.1
	10	83.3	82.8	108.6	107.1	110.8

(c) Percentage change in mesh size per kg force applied[a]

Gauge type	Force (kg)	Sample no.					Mean
		4	13	14	15	18	
ICES	4–2	−2.16	−3.51	−2.09	−3.26	−2.95	−2.79
	4–8	+0.65	0.66	0.67	0.89	0.94	0.76
EU wedge	5–2	−1.30	−1.65	−1.90	−1.26	−1.23	−1.47
	5–10	+1.04	1.02	0.95	0.76	0.89	0.93

[a]Change is measured from the values for 4 kg ICES gauge and for 5 kg EU gauge

and 8 kg. A set of mesh measurements was made with each gauge on each of five netting samples of different construction (Table 9(b)). A similar series of measurements was made on the same samples using the wedge gauge with hanging weights of 2, 5 and 10 kg (Table 9(b)).

Indicated mesh size varies significantly with the force applied by the gauge (Fig. 6). For the EU wedge gauge, mesh size is increased by approximately 1% kg^{-1} of applied vertical force in the range from 2 to 10 kg. For the ICES gauge, the mean change in mesh size per kilogram of applied longitudinal force is not constant in the range from 2 to 8 kg, being between 2 and 3.6% in the range from 2 to 4 kg force and less than 1% from 4 to 8 kg force (Table 9(c)). These percentages are calculated with respect to the values at 4 and 5 kg forces for the ICES and wedge gauges respectively.

From crossplots of Fig. 6 the spring force for the ICES gauge which produces the same measured mesh size as a given weight on the EU gauge can be determined (Fig. 7). Each

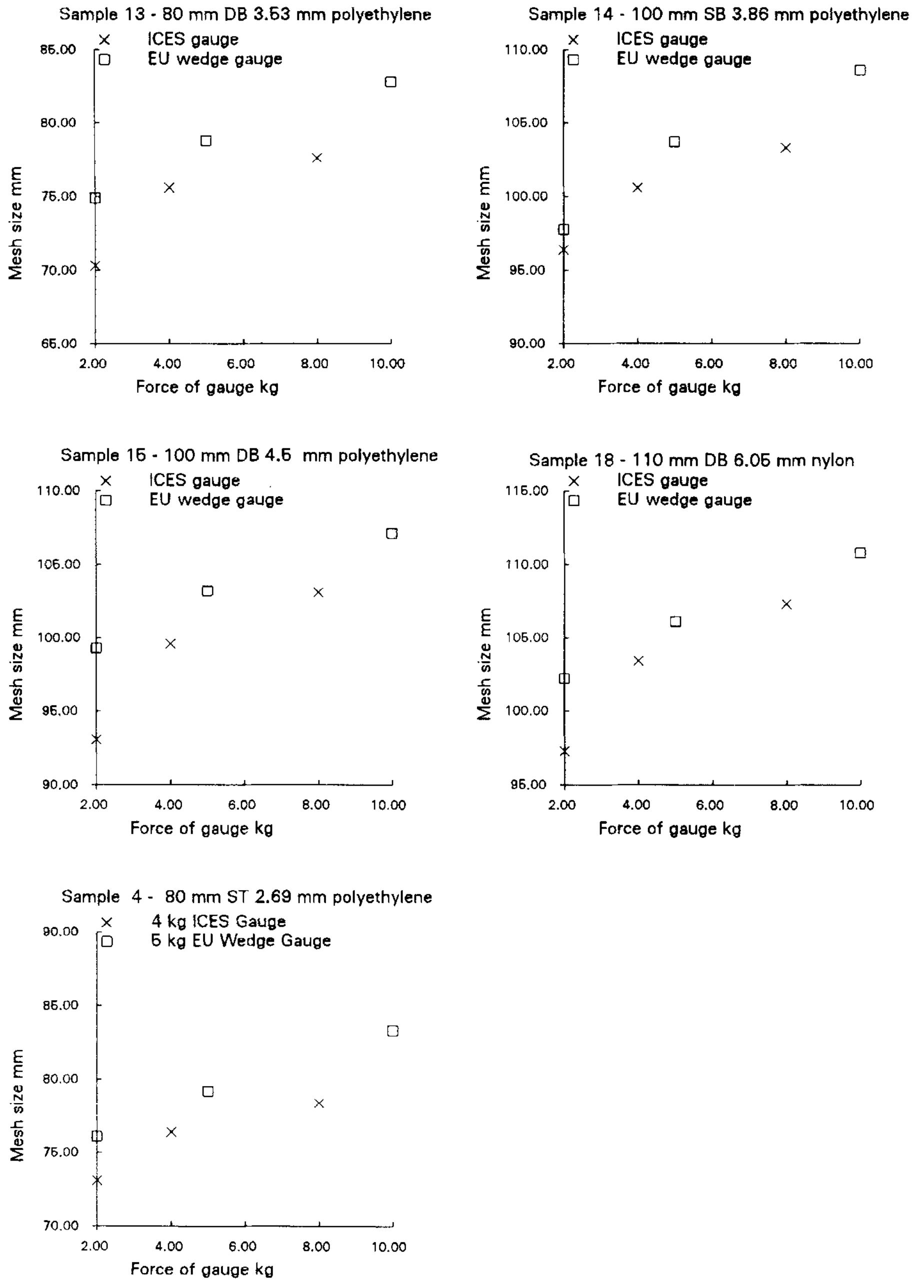

Fig. 6. Effect of applied force on mesh measurement.

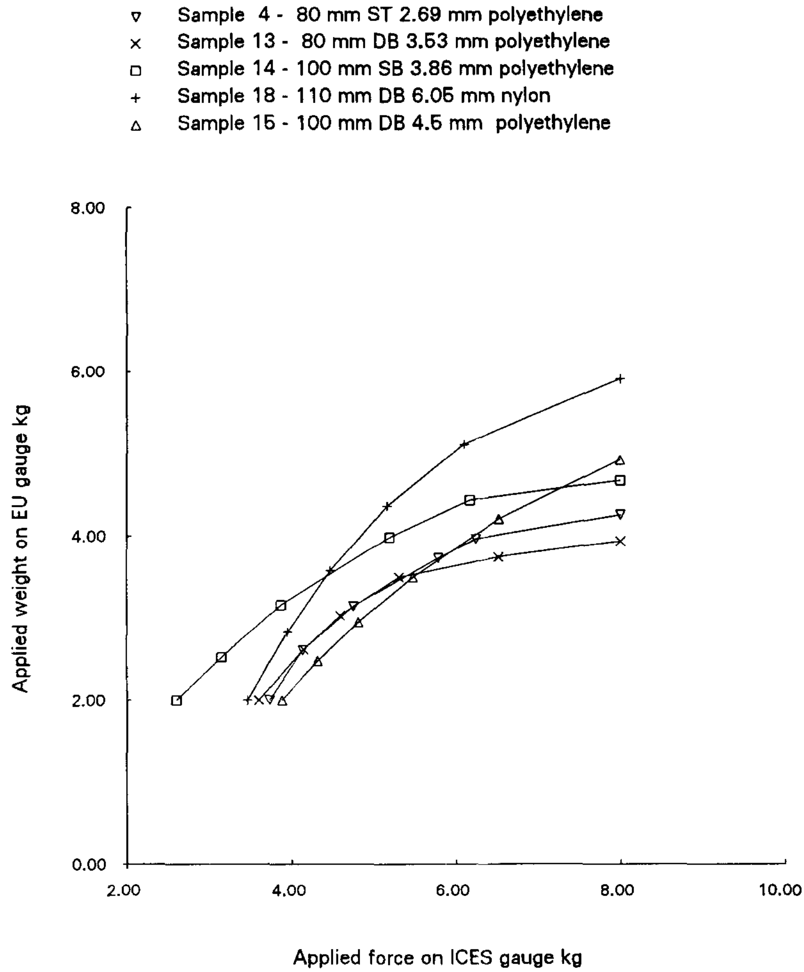

Fig. 7. Applied forces at which gauges read similar mesh sizes.

curve is appropriate to a particular sample and each point on the curve indicates the forces on each gauge which gave rise to the same measured mesh size. For four PE netting samples tested, readings equivalent to the 5 kg EU gauge can only be obtained with an ICES gauge having more than 8 kg spring force.

The forces applied to the netting by the two gauges are quite different. Schwalbe and Werner (1977) show that, under frictionless conditions, a 5 kg weight generates a longitudinal force in the plane of the netting of about 20 kg. This force will be reduced in the presence of friction and a plausible friction coefficient of 0.35 reduces the force in the netting plane to about 4 kg, equal to that generated by the standard ICES gauge. For the measurements made here it may be concluded that the friction coefficient is less than 0.35. Clearly friction will affect the readings obtained by the wedge gauge. Friction is determined by the environmental conditions and by the twine and gauge material.

Table 10
Mean value and standard deviation of 40 mesh measurements made in the N- and T-directions of sample 9 (80 mm SB 4 mm polyethylene)

Direction	Number of set			Mean
	1	2	3	
T-direction	77.7	77.6	73.3	76.2
Standard deviation	1.4	1.6	1.5	2.5
N-direction	77.8	76.7	77.2	77.2
Standard deviation	2.4	2.1	2.1	1.5

These results suggest that the ICES gauge with a 2 kg spring force is not fully extending the mesh. At higher spring forces the reading continues to increase perhaps because the material at the point of contact is deforming, the knot is tightening or the twine is elastically stretching.

In this situation there is good reason to choose a larger gauge force so that any uncertainty in gauge force (e.g. due to friction variation) will have a smaller effect on mesh size. However, if twine thickness is not taken into account in choosing the gauge force it is important that the gauge force is not so large that it causes significant elastic elongation during the measurement process. A thinner twine would then register a larger mesh size.

3.5. Choice of direction of row of meshes to be measured

European Community legislation (Anonymous, 1984) states that a row of meshes 'in the direction of the long axis of the net' shall be chosen. Three independent sets of 40 meshes were measured in both the N- and T-directions of sample 9 (80 mm single braided polyethylene netting) in order to determine whether there was any difference in the choice of row direction.

There are significant differences between the sets of measurements in the T-direction (Table 10) although it is noticeable that the standard deviation of any one set in the T-direction is less than that in the N-direction. This is because netting is manufactured with the twines running in the T-direction so that the length of bars in the same row in the T-direction is usually uniform but may vary between rows. The mean measurements along the N-direction can thus fairly represent the mesh size of the netting because the variability of the mesh size from one row to the next is present in each mean value. The standard deviation of all 120 mesh measurements in the N-direction is considerably lower than that in the T-direction since there are perhaps only three readings from a row with markedly shorter meshes, whereas there are 40 readings from that row in the T-direction.

This is a convincing demonstration that it is important to take longitudinal rows of meshes in the N-direction when determining the mean mesh size of netting, e.g. for enforcement purposes.

Table 11
The effect of soaking PE netting in water

	Netting condition	Sample number				
		1	4	8	12	13
ICES	Dry	76.8	77.7*	75.4	79.8*	75.1*
	Wet	76.9	77.1	74.9	79.0	74.3
Wedge	Dry	80.3	81.9*	79.2	83.5	80.6
	Wet	80.6	81.2	79.1	84.1	80.3

*$P<0.05$.

3.6. Effect of water on gauge performance

The aim of these measurements is not to determine whether mesh size changes when netting is wetted due to, for example, water absorption but to assess whether the operation of gauges is systematically affected when the twine is wet eg through changes in friction characteristics. The length of PE yarn constructed from relatively large diameter filaments is practically unaffected by water (Klust, 1982). Hence it is a good material to use to check for an effect on mesh gauge operation.

Five representative pieces of PE netting were selected. The samples were measured dry and then soaked for more than 24 h before further measurements were made on a different set of 40 meshes (Table 11). The 4 kg ICES gauge and the wedge gauge with 5 kg weight were both used. Of the 10 comparisons which can be made only one wedge gauge measurement and three ICES gauge measurements are significantly different at the 95% level between wet and dry conditions. These all show a reduction in mean value of mesh size when wet. Only one twine (sample no. 4) shows a significant result for both wedge and ICES gauges.

No systematic effect on gauge performance is indicated by these results.

4. Conclusions

The main factors affecting mesh measurements are the choice of method, the force applied by a gauge to the netting and the tension with which the netting is held.

The length of mesh measured between knot centres eg by tape measure is not a suitable characteristic to relate to the selectivity of fishing gear since it depends not only on opening of mesh but also on twine thickness. Detailed knowledge of the twine thickness, knot structure and other twine properties would be required to relate the length of mesh to the mesh opening.

The EU gauge with a 5 kg weight gives significantly larger values of opening of mesh than the ICES 4 kg gauge. Under controlled conditions there is a consistent relation between measurements using the two methods. However, it should be noted that the precise relation found may apply only to the specific conditions under which these measurements were made, e.g. when the meshes were held at 60° setting angle with a netting tension of 500 g per mesh.

The ICES gauge requires a spring force of at least 8 kg to achieve similar mesh openings in dry PE netting to a wedge gauge with 5 kg weight. Mesh openings change by approximately 1% for a 1 kg change in vertical force generated by the 5 kg wedge gauge. They change by rather more than this percentage per kilogram of longitudinal spring force generated by the 4 kg ICES gauge.

Changes in tension in polyethylene netting of the order of 1 kg per mesh have no significant effect on mesh measurements made with a 5 kg wedge gauge but can cause small but significant reductions in those made by a 4 kg ICES gauge: that is, if the netting is held with an increased tension then an ICES gauge will register a smaller mesh size.

Under controlled conditions the variance in a set of mesh measurements on a netting sample is similar whether an ICES or an EU wedge gauge is used. The variance is therefore likely to be caused less by the method and more by the characteristics of the netting and twine. Minimum coefficients of variation for measurements on PE netting may be in the range from 1 to 3% due to this inherent variability. Variance above this level may be due to uncontrolled measurement conditions, eg at sea. A more carefully defined measurement protocol may reduce this additional variance, if practically possible.

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